Seal strength evaluation of flexible plastic films by machine testing and human peeling

NILMANEE, Somporn, JINKARN, Tunyarut, JARUPAN, Lerpong, PISUCHPEN, Supachai and YOXALL, Alaster <http://orcid.org/0000-0002-0954-2725>

Seal Strength Evaluation of Flexible Plastic Films by Machine Testing and Human Peeling

Somporn Nilmanee[1], *Tunyarut Jinkarn*[1]*, *Lerpong Jarupan*[1], *Supachai Pisuchpen*[2], *and Alaster Yoxall*[3]

ABSTRACT: The seal strength of flexible packaging indicates both functional performance and the ease of opening. This research aims to compare the seal peeling mechanisms evaluated by human participants and standard machine tests. The tests were conducted on flexible films used for typical packaging applications, LDPE, LLDPE and Nylon/LLDPE. Human peeling was simulated through the use of novel force measurement equipment. The results showed that the maximum machine peel force set by standard test methods was generally lower than the human peel force for most sealing temperatures. In all film types no significant difference was shown between genders although for people over 65 years peel force was generally lower than for the younger cohort. The results also indicated that peeling speed of human participants was normally higher than the peeling speed set according to the machine test standard.

KEYWORDS: seal strength, packaging, human peeling, ease of opening, flexible plastic

Introduction

Manufacturers usually measure and control the seal strength of bags or pouches made from flexible packaging materials by testing peel force. Further, manufacturers usually measure seal integrity to ensure a hermetic seal and product quality control. In general the seal strength of a heat sealed flexible pouch may vary, and can depend on the types of materials used for the sealing layer, the seal temperature, dwell time and pressure of the sealing jaw [1-2]. Since seal strength is one of the most important quality characteristics for evaluating packaging performance, researchers have attempted to analyze the seal strength of flexible packaging by varying packaging materials or sealing parameters by using standard testing procedures [3-10].

Other than the force measurement through the use of testing procedures, some studies have developed measuring techniques for the human peeling force of flexible packaging and films. Canty *et al.* [11] measured finger friction between pack and finger by an observational analysis on 60 users and the result indicated that the issues surrounding accessibility of this pack format were related to dexterity not strength. Liebmann *et al.* [12] also demonstrated the assessment of the human force necessary to open peelable packaging whilst Mark *et al.* [13] investigated the

[1] Department of Packaging and Materials Technology, Faculty of Agro-Industry, Kasetsart University, 50 Ngam Wong Wan Rd, Lat Yao Chatuchak Bangkok 10900 Bangkok, TH 10900 (*Note*: Go to www.ku.ac.th for details, email: fagitvp@ku.ac.th)
[2] Department of Material Product Technology, Prince of Songkla University, Songkhla, 90110, Thailand; PSU (*Note*: Go to www.psu.ac.th for details, email: supachai.p@psu.ac.th)
[3] Art and Design Research Centre, Sheffield Hallam University, Sheffield, Howard street, S1, 1WB, UK; SHU (*Note*: Go to www.shu.ac.uk for details, email: a.yoxall@shu.ac.uk)
* Corresponding Author, Email fagitvp@ku.ac.th

forces people could apply to aluminum or plastic tear tabs of different lengths. According to this study, participants were able to apply most force to the longest aluminum tab, using the key grip.

There has also been significant interest in the openability of packaging in other formats, including blister packages, bottles, trays and glass jars. These studies have used specially designed force measurement devices for evaluating the opening forces or optical camera techniques to measure grip motions. Rowson *et al*. [14] undertook one of the earliest studies on medical blister packaging using motion-capture, grip and dexterity analysis. The results identified the four common types of grips used, and that participants generally had a preferred grip style. Moreover, the study also confirmed that dexterity decreases with age. De la Fuente, C. J. [15] undertook a study on the peeling angle of a semi-rigid tray with peelable lid. This study also covered the relationship between tab size and grip choice. The results showed that the mean peel angle fell within the theoretical optimal peel angle range for the tray (α=45°±15°). The study also showed that the grip preferences for the peeling also depended on the tab size. Work by Carus *et al*. [16] studied the initial testing of a novel multi-axial force and torque transducer for tamper-evident bottle closures. The results showed that the elderly and the young groups exhibited significantly different torque and force profiles when attempting to open the bottles. Similar work was also conducted by researchers focusing on the opening force measurement and opening postures of bottles and jars [17-26].This interest in understanding the issues around openability has led to the development of European and international guidelines on the measurement of packaging seal forces and user test panel methods. The European technical specification DD CEN/TS 15945 [26] launched in 2011 sets out a framework for ease of opening evaluation for packaging and has more recently been superseded by ISO17480. The technical specification describes a user panel test for the qualitative evaluation of a packaging performance. The specification also describes a series of possible mechanical tests that can be used to evaluate ease of opening for a pack.

Many standards exist for the testing and evaluation of packaging materials and packs such as the measurement for heat sealed soft and semi-rigid packages based on JIS Z-0238 [2], mechanical seal strength testing for round cups and bowl containers with flexible peelable lids based on ASTM F2824 [15] and standard test for seal strength of flexible barrier materials from ASTM F88 [27]. In addition, the standard DIN 55529 also provides criteria for determining seal strength of flexible packaging materials. Besides measuring of the seal strength, the peel delamination between flexible material layers can also be done via ASTM D1876, Standard Test Method for Peel Resistance of Adhesives (T-Peel Test) [28]. However, according to the established international standards, peeling setup for measuring the seal strength and measuring the peel delamination are different.

Although there are standard evaluation procedures and a significant number of studies relating to seal peel forces using recognized testing machines and procedures, the level of how well these testing procedures can accurately access the forces and speeds of peeling a sealed flexible film by humans has not yet been identified. Hence a study was proposed to measure the peel forces of a common sealed flexible packaging material using testing procedures through a standard testing machine and then to compare those peel forces to a set of measured forces derived from human testing. Elongation at break and peel speed were also compared and analyzed as part of this study along with the effects of age and gender of participants.

Materials and Methods

Sample preparation

The flexible commercial films selected for testing included a low-density polyethylene (LDPE 70 µm), linear- low-density polyethylene (LLDPE 70 µm) as well as Nylon15/LLDPE45 µm. LDPE and LLDPE were selected since they are primarily used as a sealing layer for most flexible films due to their low heat sealing temperature. The heat sealing machine used in the study was the MTMS from Japan (Fig. 1(*a*)). All films were preliminary tested to understand the relationship between seal strength vs temperature profile. After this preliminary analysis, the temperature of the MTMS sealing bars were set at 112, 114, and 116 ºC for LDPE and LLDPE and the bar temperatures for Nylon/LLDPE were set at 109, 111, 113 ºC. Seal pressure was kept constant at approximately 0.3 MPa and dwell time was controlled at one second throughout all sealed samples. The objective of these differing seal condition settings was to produce the varying seal strength for the subsequent seal strength tests.

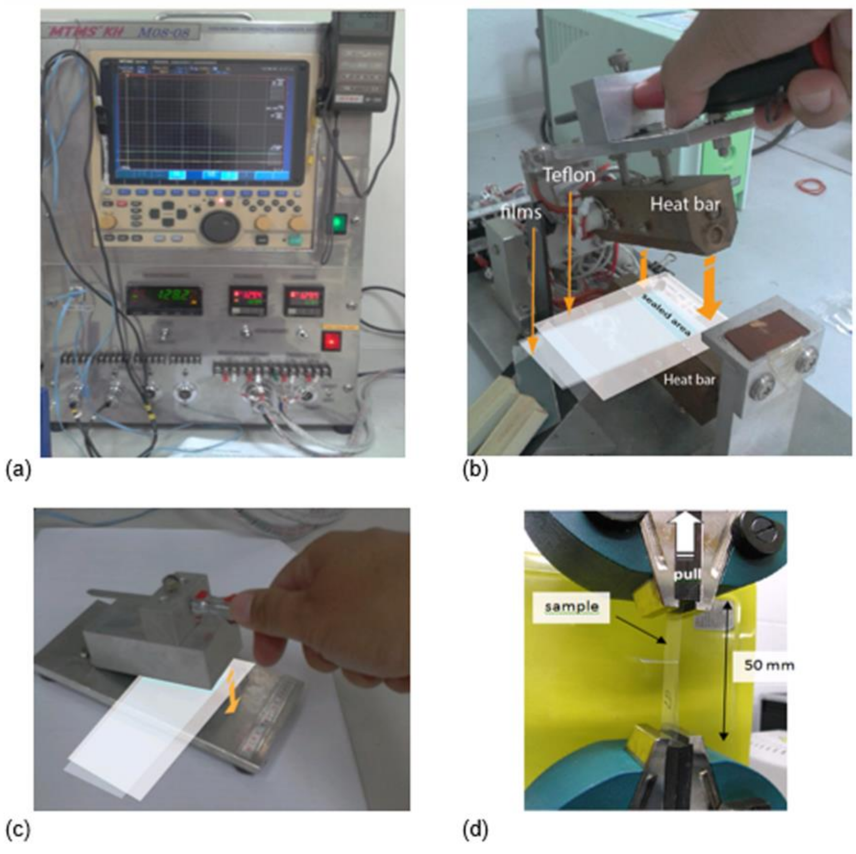


FIG. 1—*Heat seal equipment and tensile testing: heat sealing machine MTMS device, control unit (a) manual heating press (b) cooling press (c) and sample griping on universal testing machines (d).*

Seal strength measurement

Following the sealing process, all samples were kept for 48 hours at room temperature to condition the seals to achieve maximum seal strength. The sealed film samples were subsequently cut into strips of 15 mm width and 100 mm length as per ASTM F88 (2012) shown in Fig**.** 2. During the heat sealing process, Teflon sheets of 0.1 mm thickness were placed between the film and the heating jaw to prevent sticking (Fig. 1(*b*)). The sealed films were cooled in ambient conditions by the use of a cooling press as shown in Fig. 1(*c*). The seal strength and elongation at break of the commercial films were measured using a Universal Testing Machine (5900 series, Instron Ltd., Bucks, UK). Each leg of the sealed specimen was gripped in the opposite direction (180 degree) by the fixed and moving jaws of the force testing machine so the seal was equidistant between the two grips, and aligned laterally so the seal is perpendicular to the direction of movement of the grips. The loading speed of the test was set at 10 inches/min (254 mm/ min) under a loading cell of 5KN. After the test, maximum force required to tear apart the seal was recorded. The distance of an initial grip of the sample at the machine was 50 mm for all tests (Fig. 1(*d*)).

Human force measurement

For the human force measurement test, age, gender, weight (kg), height (cm) and size of palm (width and length) of participants were recorded along with the peak force and the average peel speed. This test used a digital force gauge (Desik, DS-500, Germany) to measure the peak force of each participant, whilst a high speed camera (Model: Photron, SA3, USA) and Photron FASTCAM Viewer software with the frame rate as 1000 fps, resolution at 1024 x 1024 were used to analyze the peel elongation. Each participant was asked to pull a sealed sample perpendicular to the seal area by fixing the end of each sample with the force gauge and holding this in one hand whilst pulling the other end with the other hand (Fig. 3(*a*)). The peel angle was controlled while testing at 180 degree. The seal peel with the digital force gauge was conducted on the table top to force the participant to peel toward the opposite side at keeping the peel level. Force of pulling the seal was undertaken for both hands of participants. Elongation of the films was measured by placing a ruler along with the pulling distance (Fig. 3(*b*)). Video analysis of the peeling from the high speed camera recorded a total time required to complete the seal and film elongation starting from an initial grip until the end of pulling was also recorded in order to calculate the peel speed of the test. The statistical analysis of the mean values between human and machine testing was conducted through analysis of variance (ANOVA) using SPSS version 17 and the post hoc tests were conducted through Duncan's multiple-range test. Testing procedure conducted with human was approved though the internal review board committee (Sheffield Hallam University Research Ethics committee) and before conducting any experiment, testing procedures were explained to all participants and consent gained.

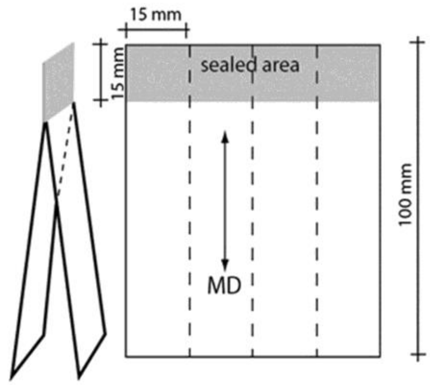
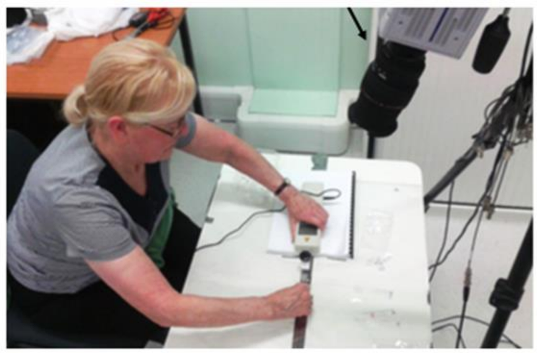
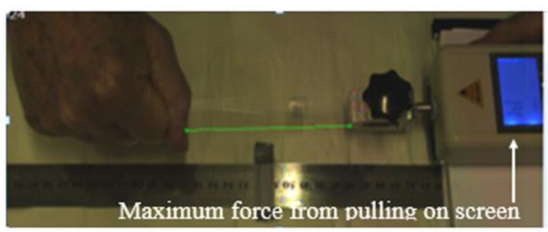


FIG. 2—*Sample size*



(a)



(b)

FIG. 3—*Setup of human force measurement: force measurement equipment and setup (a) and film elongation evaluation (b).*

Experimental Results

Participants of the test

A total of 24 participants were recruited from the Sheffield area of the UK with the description of the participants shown in Table 1. Participants were classified into four age groups. During the experiment, the test was conducted with one participant from each age group at a time. Differences of maximum peeling forces and peeling speeds were compared between each set of participant in each age group. A minimum of 5 set of participants were used for the test since the differences of physical performance such as weight, height and average hand dimension as well as peeling forces and peeling speeds among each participant in each age group cohort were not significantly different.

TABLE 1—*Participants for the test.*

Age (year)	Male % (*n*)	Female % (*n*)	Total % (*n*)	Average weight (kg)	Average height (cm)	Average palm dimension length x width (cm)
18-30	17(4)	12(3)	29(7)	71.5(±8.88)	172.2(±9.98)	17.6(±1.43) x 8.4(±0.90)
31-50	8(2)	17(4)	25(6)	83.8(±15.87)	173.0(±5.97)	18.1(±0.20) x 8.1(±0.37)
51-65	4(1)	17(4)	21(5)	96.2(±13.54)	164.5(±9.45)	17.9(±1.21) x 7.9(±0.68)
66- 85	8(2)	17(4)	25(6)	68.6(±14.62)	164.0(±4.86)	17.4(±0.49) x 7.9(±0.49)
Total/Average	37(9)	63(15)	100(24)	80.0 (±10.94)	168.4(±4.19)	17.7(±0.27) x 8.1(±0.20)

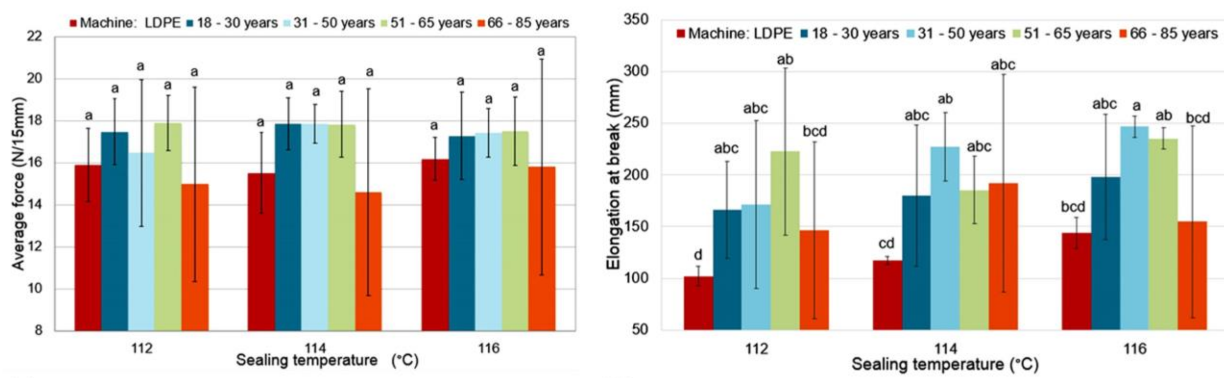
Comparison of human and machine peel forces and elongation at break

Peel forces of participants compared to machine peel forces for different seal temperatures of each sealed film are shown in Fig. 4-6. Statistically significant differences ($p<0.05$) are displayed via different letters on the top of each bar in each figure. According to the results, average maximum machine peel forces of the seal for LDPE and LLDPE 70µm and Nylon15/LLDPE45 at 112ºC were 15.91, 9.36 and 10.40 N/15mm respectively. Although, LLDPE generally produces a stronger seal than LDPE due to the compact molecular structure, for this test, LDPE showed the highest seal strength at low seal temperature since its heat transfer rate is higher than LLDPE and multilayer Nylon/LLDPE. Therefore, higher heat transfer rate leads to a higher surface temperature and will result in a stronger seal for LDPE. When the seal temperature is increased, we can see that Nylon/LLDPE shows a stronger seal than LDPE because the sealing layer of LLDPE in the laminated structure received high heat and produced a strong molecular bonding.

Seal strength derived from machine testing can be predicted based on materials properties and seal condition, however, human seal peel is quite complex. Based on the results, at a low seal strength of a low sealing temperature, such as for LLDPE at 112ºC and Nylon/LLDPE at 109 ºC, maximum machine peel forces were found to be significantly lower than the maximum measured human peel forces. However, the elderly cohort (of over 65 year old) showed lower seal strength than other groups, therefore, seal peel force of this group may not be significantly different from the machine peeling force and may indeed be lower than that derived from the machine tests.

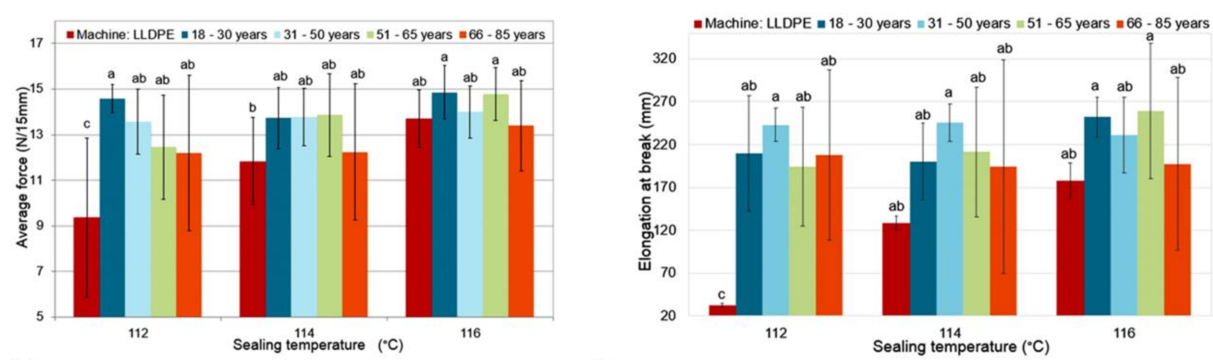
If we compare the results of human tests for the differing age groups, minimal variation for the peel force was found. The cohort who were over 65 years old did show lower peel forces than other age groups although no significant difference was found. For machine peeling, maximum peel force was visibly increased along with the seal temperature, however, maximum human peel forces show not much difference among seal temperatures except for the laminated film sample where the peel forces were noticeably increased by the increase of the seal temperature. After comparing between the left and the right hand pulling of human during the seal peel testing, maximum forces form both hands were not significantly different.

For elongation at break for LDPE and LLDPE films, human peeling from all age groups showed more film elongation, but no significant difference was found between machine peel elongation and the human peel elongation, except for LLDPE at 112ºC and this might be due to the fact that LLDPE can stretch more than other types of films, especially at lower sealing temperatures. Further, since the measured human peel force was generally higher than the machine peel force, more human peel elongation was significantly detected. However, for Nylon/LLDPE, elongation at break values derived from the machine testing trend to be higher than from human peeling. Fig.7-9 compares the peel force and elongation at break between the machine and human tests classified by gender, and the results confirmed that the machine peel force is generally lower than the human peel force especially at a low sealing temperature. It can also be noted that, although slightly different found, men and women showed no significant difference in seal peel strength.



(a) (b)

FIG. 4—*Peel force and elongation at break of machine and human classified by age groups for LDPE 70µm: peel force (a) and elongation at break (b) (Means not sharing a letter are significantly different (p<0.05)).*



(a) (b)

FIG. 5—*Peel force and elongation at break of machine and human classified by age groups for LLDPE 70µm: peel force (a) and elongation at break (b) (Means not sharing a letter are significantly different (p<0.05)).*

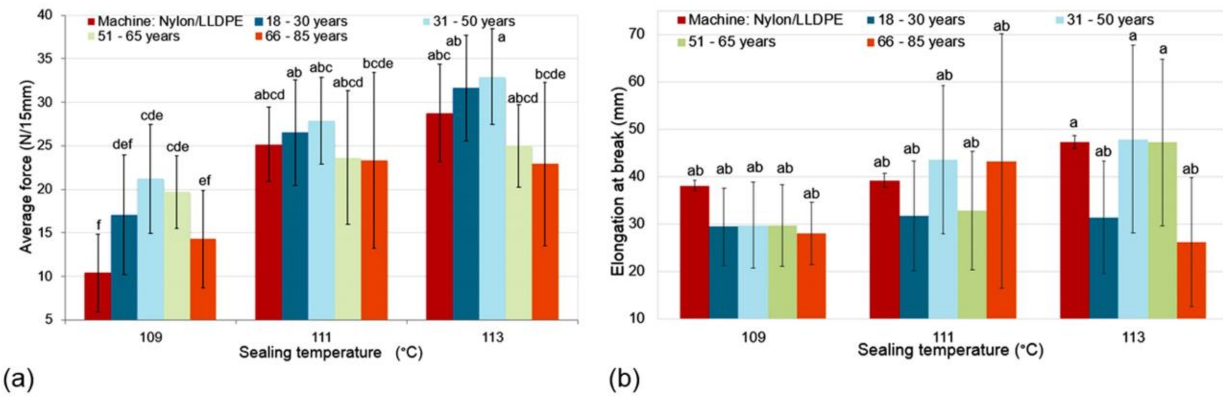
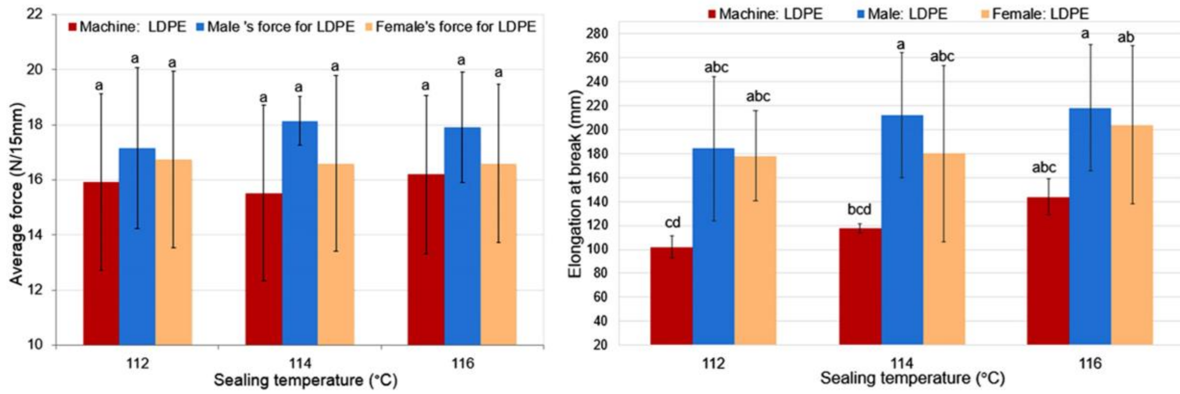


FIG. *6—Peel force and elongation at break of machine and human classified by age groups for Nylon15/LLDPE 45μm: peel force (a) and elongation at break (b) (Means not sharing a letter are significantly different (p<0.05)).*

Machine peel forces are found to be lower than the peel forces of humans and this could be due to the fact that humans tend to apply more force with higher speeds to initiate the opening of the seal. It is also very interesting that the force applied through the machine grip is evenly distributed along the end of the sealed film whereas the peel forces of human might not show the same pattern depending on the grips and positions of palm and fingers. According to the observation, grip postures of human are be different form each other and this could also affect the variation of peel forces and elongation at break. Moreover, elongation at break values derived from machine testing are significantly lower than human peeling. This might be a result from higher initial force applied by human peeling. The amount of film extension is not only dependent on the amount of force applied, but also depends on the film properties. In this research, sealed film form LDPE and LLDPE exhibit higher seal elongations when compared to a multilayer structure of Nylon/LLDPE.

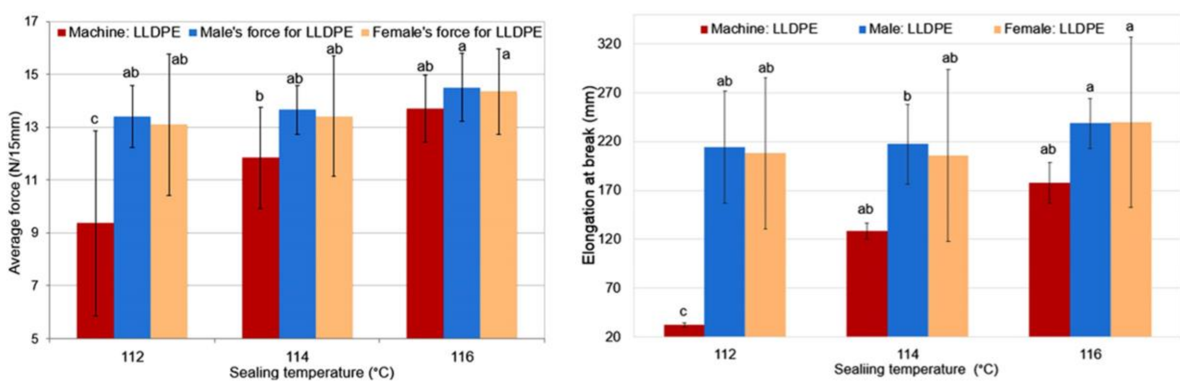
The study indicated that maximum peel forces of humans vary, and that older people of more than 65 years of age, show a lower peel force and take a longer time to complete the peel when compared to other age groups. According to the results, in most cases, men show slightly higher peel forces than women. This is in accordance with other research [29-30] which mentioned that human strength capability of opening packages depends on age. Rowson and Yoxall [30] also reported that typically, women chose a grip that maximized their opportunity of opening the closure and that this grip choice was more limited than that available for men. According to Voorbij and Steenbekkers [18], gender influenced twisting force and opening toque when opening a jar of jam. Yoxall *et al.* [21] studied squeeze strength with bottles and confirmed that women produced consistently lower forces than men.

From this study it was also shown that the elongation of the seal is also different from machine testing and human peeling. This could mainly be due to the mechanical properties of the films and the amount of forces applied. The elongation at break of LDPE and LLDPE sealed films are significantly higher than the Nylon film since this film can better stretch due to its lower glass transition temperature [31]. Generally, a higher applied force will result in a higher more extension of the sealed film. This situation can be found for LDPE and LLDPE in human peeling, but this was not the case for the multilayer film of Nylon/LLDPE in this study. Although the forces of human peeling for a multilayer film is quite high compared to the machine forces, the elongation might not correspond to the forces applied due to the low elasticity properties of Nylon [31]. The force of human peeling is also not consistently held stable when peeling the sealed films and the film might return back to its original length. However, since the force applied by the machine is consistent and therefore, the change to return back to its original length is lower and this makes a strong film such as Nylon stretch more under the machines peeling.



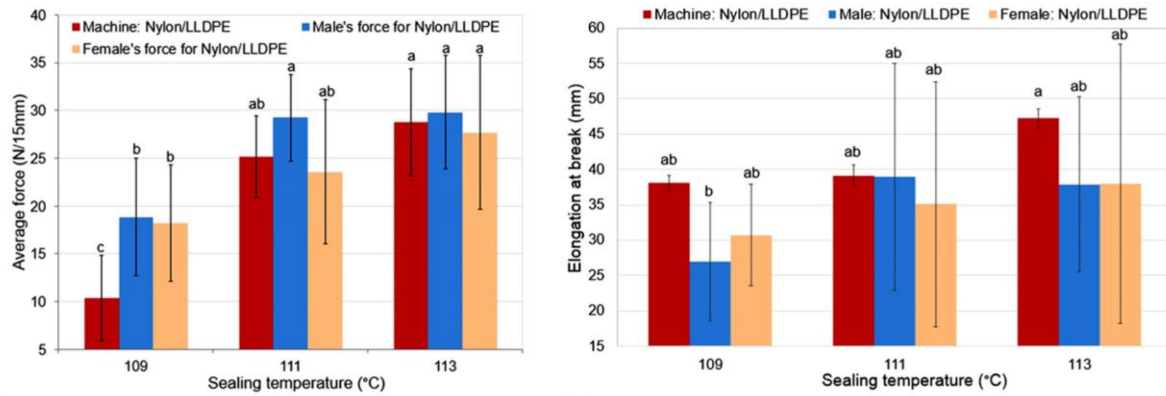
(a) (b)

FIG. 7—*Peel force and elongation at break of machine and human classified by genders for LDPE 70 µm*: *peel force (a) and elongation at break (b) (Means not sharing a letter are significantly different (p<0.05)).*



(a) (b)

FIG. *8*—*Peel force and elongation at break of machine and human classified by genders for LLDPE 70 µm*: *peel force (a) and elongation at break (b). (Means not sharing a letter are significantly different (p<0.05)).*



(a) (b)

FIG. *9—Peel force and elongation at break of machine and human classified by genders for Nylon15/LLDPE 45µm: peel force (a) and elongation at break (b) (Means not sharing a letter are significantly different (p<0.05)).*

Comparison of human and machine peeling speed

The peeling rate of the machine test was set according to ASTM F88 (2012) at 10 in/min. Fig. 10-12 show peeling rate of participants at different seal temperatures. That peel speed of human peeling was derived from the calculation of dividing the pulling distance until the seal is separated apart by the peeling time. According to the results, the human peeling rate is significant higher than that from the machine test and the differences depend on the age group. Peeling rate is quite low for the age group of 51-65 and 66-80 cohort. In addition, the 31-50 year old cohort seems to shows the highest peeling rate followed by the 18-30 cohort.

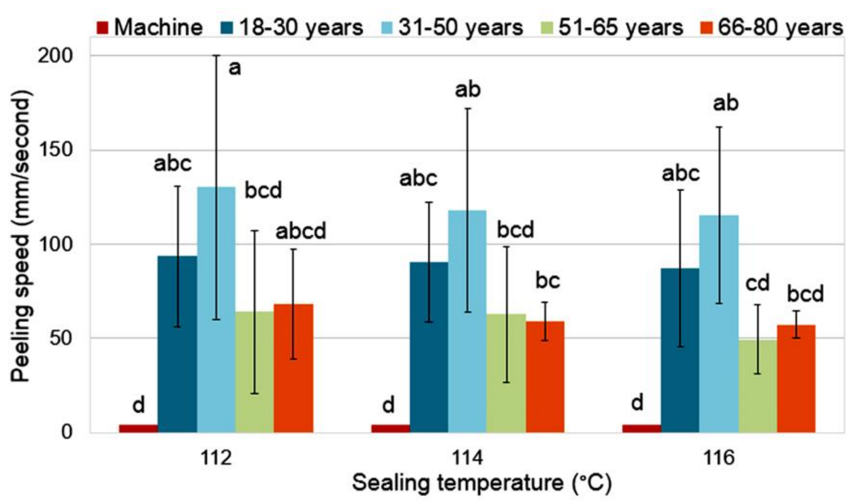


FIG. 10—*Peel rate comparison of machine and human for LDPE 70 µm.*
(Means not sharing a letter are significantly different (p<0.05)).

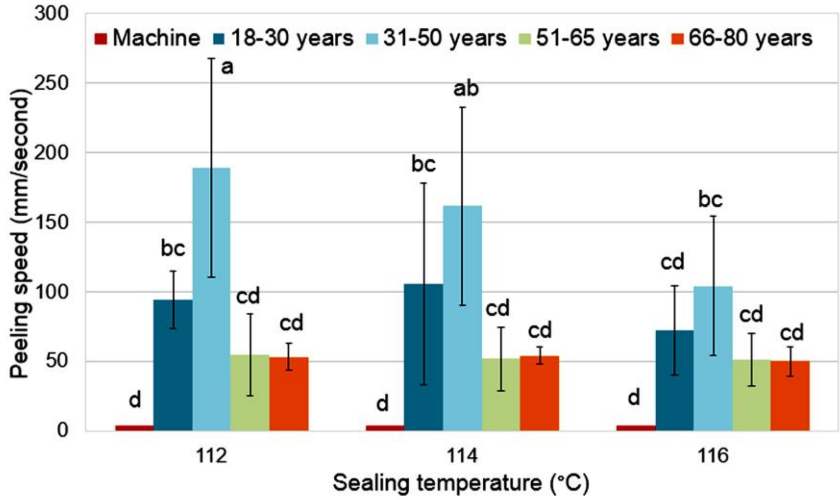


FIG. 11—*Peel rate comparison of machine and human for LLDPE 70 µm. (Means not sharing a letter are significantly different (p<0.05)).*

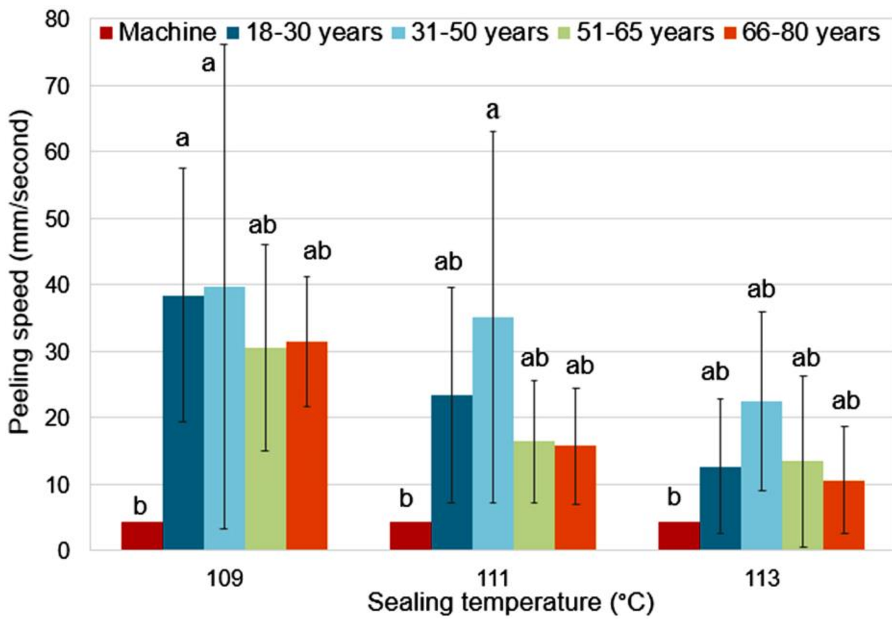


FIG. 12—*Peel rate comparison of machine and human for Nylon15/LLDPE 45 µm. (Means not sharing a letter are significantly different (p<0.05)).*

Examining the results of peel speed, the human peel speed is significantly faster than that of the machine tests. The 51 year and older participants tended to peel at a lower speed than the cohort of under 50 year olds. According to the results, peel speeds and peel forces are correlated for the same materials, the higher the peeling speed, the higher the peeling forces. This finding is also correlated with Tetsuya *et al*. [32] who showed an effect of peel rate on seal strength of CPP and OPP films by setting peel speeds at 20, 100 and 300 mm/min and evaluating the seal strength. Moreover, Liebmann *et al*. [12] has reported that peel speed influenced tear initiation force of a recloseable thermoforming tray. In addition, the results also revealed that the peeling speed of the human for LDPE and LLDPE was even higher than for Nylon/LLDPE. This might due to the fact that LDPE and LLDPE generally exhibit higher elongation than Nylon/LLDPE when apply the same amount of peel forces.

Conclusions

This study showed the differences of seal strength testing results between standard testing procedure through common testing machine and that of human assessment. According to the study, the following conclusion can be addressed.

- Material properties, sealing process parameters, physical capability of human as well as age and gender are essential factors for consumer openability of thin films.
- Humans generally showed higher peeling forces with faster peeling speed when compared with the testing machine operated according to established testing standards.
- Maximum peel force of the human depends on age, gender, posture of the grip and other physical strength factors.
- It can also importantly be seen that machine tests may not be effectively applied for predicting human peelability of sealed films. Machine tests tend to predict lower opening forces and peel at lower speeds than humans. Therefore, machine test should be adjusted to better reflect human openability such as by setting to pull the film faster.

Acknowledgement

The authors would like to thank the Office of the Higher Education Commission, Thailand for its financial support the program Strategic Scholarships Fellowships Frontier Research Networks, Specific for Southern region (CHE-SSR-PH.D-SW). In addition, Dr. Kazuo Hishinuma was highly appreciated for the MTMS device.

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